Small Package, High Performance, Asynchronies Boost for 10 WLED Driver

General Description
The RT9293 is a high frequency, asynchronous boost converter. The internal MOSFET can support up to 10 White LEDs for backlighting and OLED power application, and the internal soft start function can reduce the inrush current. The device operates with 1-MHz fixed switching frequency to allow small external components and to simplify possible EMI problems. For the protection, the RT9293A provides 50V OVP and the RT9293B provides 50V/20V OVP to allow inexpensive and small-output capacitors with lower voltage ratings. The LED current is initially set with the external sense resistor \( R_{\text{SET}} \). The RT9293 is available in the tiny package type TSOT-23-6 and WDFN-8L 2x2 packages to provide the best solution for PCB space saving and total BOM cost.

Ordering Information
- **Package Type**
  - J6 : TSOT-23-6
  - QW : WDFN-8L 2x2 (W-Type)
- **Lead Plating System**
  - G : Green (Halogen Free and Pb Free)
- **OVP Voltage**
  - Default : 50V (RT9293A/B)
  - 20 : 20V (RT9293B)
- **Feedback Voltage Reference**
  - A : 104mV
  - B : 300mV

Note:
- Richtek products are:
  - RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
  - Suitable for use in SnPb or Pb-free soldering processes.

Features
- **VIN Operating Range**: 2.5V to 5.5V
- **Internal Power N-MOSFET Switch**
- **Wide Range for PWM Dimming** (100Hz to 200kHz)
- **Minimize the External Component Counts**
- **Internal Soft Start**
- **Internal Compensation**
- **Under Voltage Protection**
- **Over Voltage Protection**
- **Over Temperature Protection**
- **Small TSOT-23-6 and 8-Lead WDFN Packages**
- **RoHS Compliant and Halogen Free**

Applications
- Cellular Phones
- Digital Cameras
- PDAs and Smart Phones and MP3 and OLED.
- Portable Instruments

Pin Configurations
(TOP VIEW)
- VIN : 1
- VOUT : 2
- EN : 3
- GND : 4
- LX : 5
- NC : 6
- FB : 7
- TSOT-23-6
- GND : 1
- VIN : 2
- VOUT : 3
- EN : 4
- WDFN-8L 2x2

Marking Information
For marking information, contact our sales representative directly or through a Richtek distributor located in your area.
Typical Application Circuit

![Typical Application Circuit Diagram](image)

Functional Pin Description

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Pin Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT9293 GJ6</td>
<td>1</td>
<td>LX</td>
</tr>
<tr>
<td>RT9293 GQW</td>
<td>2</td>
<td>1, 5, 9 (Exposed pad)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>--</td>
<td>7</td>
<td>NC</td>
</tr>
</tbody>
</table>

Function Block Diagram

![Function Block Diagram](image)
Absolute Maximum Ratings  (Note 1)

- Supply Input Voltage, $V_{IN}$
- Switching Pin, $L_X$
- $V_{OUT}$
- Other Pins
- Power Dissipation, $P_D @ T_A = 25^\circ C$
- $TSOT-23-6$
- $WDFN-8L 2x2$
- Package Thermal Resistance  (Note 2)
- $TSOT-23-6, \theta_{JA}$
- $WDFN-8L 2x2, \theta_{JA}$
- $WDFN-8L 2x2, \theta_{JC}$
- Lead Temperature (Soldering, 10 sec.)
- Junction Temperature
- Storage Temperature Range

Recommended Operating Conditions  (Note 3)

- Junction Temperature Range
- Ambient Temperature Range

Electrical Characteristics

($V_{IN} = 3.7V, C_{IN} = 2.2\mu F, C_{OUT} = 0.47\mu F, I_{OUT} = 20mA, L = 22\mu H, T_A = 25^\circ C$, unless otherwise specified)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>$V_{IN}$</td>
<td></td>
<td>2.5</td>
<td>--</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Under Voltage Lock Out</td>
<td>$V_{UVLO}$</td>
<td></td>
<td>2</td>
<td>2.2</td>
<td>2.45</td>
<td>V</td>
</tr>
<tr>
<td>UVLO Hysteresis</td>
<td>--</td>
<td></td>
<td>0.1</td>
<td>--</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>Quiescent Current</td>
<td>$I_Q$</td>
<td>$FB = 1.5V$, No Switching</td>
<td>--</td>
<td>400</td>
<td>600</td>
<td>mA</td>
</tr>
<tr>
<td>Supply Current</td>
<td>$I_{IN}$</td>
<td>$FB = 0V$, Switching</td>
<td>--</td>
<td>1</td>
<td>2</td>
<td>mA</td>
</tr>
<tr>
<td>Shutdown Current</td>
<td>$I_{SHDN}$</td>
<td>$V_{EN} &lt; 0.4V$</td>
<td>--</td>
<td>1</td>
<td>4</td>
<td>mA</td>
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<tr>
<td>Line Regulation</td>
<td>$V_{IN}$</td>
<td>3 to 4.3V</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>%</td>
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<tr>
<td>Load Regulation</td>
<td></td>
<td>1mA to 20mA</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>%</td>
</tr>
<tr>
<td>Operation Frequency</td>
<td>$f_{OSC}$</td>
<td></td>
<td>0.75</td>
<td>1</td>
<td>1.25</td>
<td>MHz</td>
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<tr>
<td>Maximum Duty Cycle</td>
<td></td>
<td></td>
<td>90</td>
<td>92</td>
<td>--</td>
<td>%</td>
</tr>
<tr>
<td>Clock Rate</td>
<td></td>
<td></td>
<td>0.1</td>
<td>--</td>
<td>200</td>
<td>kHz</td>
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<tr>
<td>Feedback Reference Voltage</td>
<td>$V_{REF}$</td>
<td></td>
<td>94</td>
<td>104</td>
<td>114</td>
<td>mV</td>
</tr>
<tr>
<td>Temperature</td>
<td>$R_{DS(ON)}$</td>
<td></td>
<td>285</td>
<td>300</td>
<td>315</td>
<td>mV</td>
</tr>
</tbody>
</table>

To be continued
Note 1. Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

Note 2. $\theta_{JA}$ is measured in the natural convection at $T_A = 25^\circ C$ on a low effective single layer thermal conductivity test board of JEDEC 51-3 thermal measurement standard. The case point of $\theta_{JC}$ is on the expose pad for the WDFN package.

Note 3. The device is not guaranteed to function outside its operating conditions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN Threshold Voltage</td>
<td>$V_{IH}$</td>
<td></td>
<td>1.4</td>
<td>--</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>EN Threshold Voltage</td>
<td>$V_{IL}$</td>
<td></td>
<td>--</td>
<td>--</td>
<td>0.5</td>
<td>V</td>
</tr>
<tr>
<td>EN Sink Current</td>
<td>$I_{IH}$</td>
<td></td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>$\mu$A</td>
</tr>
<tr>
<td>EN Hysteresis</td>
<td>--</td>
<td></td>
<td>0.1</td>
<td>--</td>
<td>--</td>
<td>V</td>
</tr>
<tr>
<td>Over-Voltage Threshold</td>
<td>$V_{OVP}$</td>
<td></td>
<td>42</td>
<td>46</td>
<td>50</td>
<td>V</td>
</tr>
<tr>
<td>Over-Voltage Threshold</td>
<td>$V_{OVP}$</td>
<td>$OVP = 50V$</td>
<td>16</td>
<td>17.5</td>
<td>20</td>
<td>V</td>
</tr>
<tr>
<td>Over-CURRENT Threshold</td>
<td>$I_{OCP}$</td>
<td></td>
<td>1</td>
<td>1.2</td>
<td>--</td>
<td>A</td>
</tr>
<tr>
<td>OTP</td>
<td>$T_{OTP}$</td>
<td></td>
<td>--</td>
<td>160</td>
<td>--</td>
<td>$^\circ$C</td>
</tr>
<tr>
<td>OTP</td>
<td>$T_{OTP}$</td>
<td></td>
<td>--</td>
<td>30</td>
<td>--</td>
<td>$^\circ$C</td>
</tr>
<tr>
<td>Shutdown Delay</td>
<td>$T_{SHDN}$</td>
<td></td>
<td>--</td>
<td>20</td>
<td>--</td>
<td>ms</td>
</tr>
</tbody>
</table>
Typical Operating Characteristics

**Efficiency vs. Output Current**
- Efficiency (%) vs. Output Current (A)
- \( V_{\text{IN}} = 4.5\,\text{V} \)
- \( V_{\text{OUT}} = 10\,\text{V} \)

**Efficiency vs. Input Voltage**
- Efficiency (%) vs. Input Voltage (V)
- \( I_{\text{LOAD}} = 30\,\text{mA} \)
- \( I_{\text{LOAD}} = 20\,\text{mA} \)
- \( I_{\text{LOAD}} = 10\,\text{mA} \)
- \( V_{\text{OUT}} = 34\,\text{V} \)

**Output Voltage vs. Output Current**
- Output Voltage (V) vs. Output Current (mA)
- \( V_{\text{IN}} = 3.7\,\text{V}, V_{\text{OUT}} = 34\,\text{V} \)

**Quiescent Current vs. Input Voltage**
- Quiescent Current (µA) vs. Input Voltage (V)
- \( V_{\text{FB}} = 1.5\,\text{V} \)

**Frequency vs. Input Voltage**
- Frequency (kHz) vs. Input Voltage (V)
- \( I_{\text{LED}} = 20\,\text{mA} \)
- \( V_{\text{IN}} = 3.7\,\text{V}, I_{\text{LED}} = 20\,\text{mA} \)

**Frequency vs. Temperature**
- Frequency (kHz) vs. Temperature (°C)
**Enable Threshold vs. Input Voltage**

Reference Voltage vs. Input Voltage

Reference Voltage vs. Temperature

Reference Voltage vs. Output Current

Enable Threshold vs. Input Voltage

LED Current vs. Duty

Power On from EN

- **Reference Voltage vs. Input Voltage**
  - V_{OUT} = 34V, I_{OUT} = No Load
  - 10WLED, I_{LED} = 20mA

- **Reference Voltage vs. Temperature**
  - V_{IN} = 3V
  - V_{IN} = 3.7V
  - V_{IN} = 4.2V
  - I_{LED} = 20mA

- **Reference Voltage vs. Output Current**
  - V_{IN} = 3V
  - V_{IN} = 3.7V
  - V_{OUT} = 34V

- **Enable Threshold vs. Input Voltage**
  - Rising
  - Falling

- **LED Current vs. Duty**
  - f = 200Hz
  - f = 2kHz
  - f = 20kHz
  - f = 200kHz

- **Power On from EN**
  - V_{EN} (2V/Div)
  - V_{OUT} (10V/Div)
  - V_{IN} = 3.7V, I_{LED} = 20mA
  - V_{IN} = 3.7V, I_{LED} = 20mA
**Power Off from EN**

- **VIN**: 3.7V, **ILED**: 20mA

**Ripple Voltage**

- **VIN**: 3.7V, **ILED**: 20mA

---

**PWM Dimming from EN**

- **VIN**: 3.7V, **ILED**: 20mA

**PWM Dimming from EN**

- **VIN**: 3.7V, **ILED**: 20mA
Applications Information

LED Current Setting
The loop of Boost structure will keep the FB pin voltage equal to the reference voltage $V_{REF}$. Therefore, when $R_{SET}$ connects FB pin and GND, the current flows from $V_{OUT}$ through LED and $R_{SET}$ to GND will be decided by the current on $R_{SET}$, which is equal to following equation:

$$I_{LED} = \frac{V_{REF}}{R_{SET}}$$

Dimming Control

a. Using a PWM Signal to EN Pin
For the brightness dimming control of the RT9293, the IC provides typically 300mV feedback voltage when the EN pin is pulled constantly high. However, EN pin allows a PWM signal to reduce this regulation voltage by changing the PWM duty cycle to achieve LED brightness dimming control. The relationship between the duty cycle and FB voltage can be calculated as following equation:

$$V_{FB} = \text{Duty} \times 300\text{mV}$$

Where

Duty = duty cycle of the PWM signal
300mV = internal reference voltage

As shown in Figure 1, the duty cycle of the PWM signal is used to cut the internal 300mV reference voltage. An internal low pass filter is used to filter the pulse signal. And then the reference voltage can be made by connecting the output of the filter to the error amplifier for the FB pin voltage regulation.

However, the internal low pass filter 3db frequency is 500Hz. When the dimming frequency is lower than 500Hz, $V_A$ is also a PWM signal and the LED current is controlled directly by this signal. When the frequency is higher than 500Hz, PWM is filtered by the internal low pass filter and the $V_A$ approach a DC signal. And the LED current is a DC current which eliminate the audio noise. Two figures of PWM Dimming from EN are shown in Typical Operating Characteristics section and the PWM dimming frequency is 200Hz and 20kHz respectively.

But there is an offset in error amplifier which will cause the $V_A$ variation. In low PWM duty signal situation, the filtered reference voltage is low and the offset can cause bigger variation of the output current. So the RT9293A is not recommend to be dimming by the EN pin. For the RT9293B, the minimum duty vs frequency is listed in following table.

<table>
<thead>
<tr>
<th>Dimming frequency</th>
<th>Duty Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500Hz</td>
<td>4%</td>
</tr>
<tr>
<td>&gt; 500Hz</td>
<td>10%</td>
</tr>
</tbody>
</table>

b. Using a DC Voltage
Using a variable DC voltage to adjust the brightness is a popular method in some applications. The dimming control using a DC voltage circuit is shown in Figure 2. As the DC voltage increases, the current flows through $R_3$ increasingly and the voltage drop on $R_3$ increase, i.e. the LED current decreases. For example, if the VDC range is from 0V to 2.8V and assume the RT9293 is selected which $V_{REF}$ is equal to 0.3V, the selection of resistors in Figure 2 sets the LED current from 21mA to 0mA. The LED current can be calculated by the following equation.

$$I_{LED} = \frac{R_3 \times (V_{DC} - V_{REF})}{R_4}$$

Figure 1. Block Diagram of Programmable FB Voltage Using PWM Signal
Figure 2. Dimming Control Using a DC Voltage
c. Using a Filtered PWM signal

Another common application is using a filtered PWM signal as an adjustable DC voltage for LED dimming control. A filtered PWM signal acts as the DC voltage to regulate the output current. The recommended application circuit is shown as Figure 3. In this circuit, the output ripple depends on the frequency of PWM signal. For smaller output voltage ripple (<100mV), the recommended frequency of 2.8V PWM signal should be above 2kHz. To fix the frequency of PWM signal and change the duty cycle of PWM signal can get different output current. The LED current can be calculated by the following equation:

$$I_{LED} = \frac{V_{REF} - R3 \times (V_{PWM} \times \text{Duty} - V_{REF})}{R4 + R_{DC}}$$

By the above equation and the application circuit shown in Figure 3, and assume the RT9293 is selected which $V_{REF}$ is equal to 0.3V. Figure 4 shows the relationship between the LED current and PWM duty cycle. For example, when the PWM duty is equal to 60%, the LED current will be equal to 8.6mA. When the PWM duty is equal to 40%, the LED current will be equal to 12.7mA.

**Constant Output Voltage Control**

The output voltage of the R9293 can be adjusted by the divider circuit on the FB pin. Figure 5 shows the application circuit for the constant output voltage. The output voltage can be calculated by the following equations:

$$V_{OUT} = V_{REF} \times \frac{R1 + R2}{R2} ; \ R2 > 10k$$

**Figure 3. Dimming Control Using a Filtered PWM Signal**

**Figure 4. PWM Duty Cycle vs. LED Current**

**Figure 5. Constant Output Voltage Application**

**Figure 6. Application for Driving 3 X 13 WLEDs**
Application for Driving 3 x 13 WLEDs
The RT9293 can drive different WLEDs topology. For example, the Figure 6 shows the 3x13 WLEDs and total current is equal to 260mA. The total WLEDs current can be set by the \( R_{\text{SET}} \) which is equal to following equation.

\[
I_{\text{Total}} = \frac{V_{\text{REF}}}{R_{\text{SET}}}
\]

Power Sequence
In order to assure the normal soft start function for suppressing the inrush current the input voltage should be ready before EN pulls high.

Soft-Start
The function of soft-start is made for suppressing the inrush current to an acceptable value at the beginning of power-on. The RT9293 provides a built-in soft-start function by clamping the output voltage of error amplifier so that the duty cycle of the PWM will be increased gradually in the soft-start period.

Current Limiting
The current flow through inductor as charging period is detected by a current sensing circuit. As the value comes across the current limiting threshold, the N-MOSFET will be turned off so that the inductor will be forced to leave charging stage and enter discharging stage. Therefore, the inductor current will not increase over the current limiting threshold.

OVP/UVLO/OTP
The Over Voltage Protection is detected by a junction breakdown detecting circuit. Once \( V_{\text{OUT}} \) goes over the detecting voltage, LX pin stops switching and the power N-MOSFET will be turned off. Then, the \( V_{\text{OUT}} \) will be clamped to be near \( V_{\text{OVP}} \). As the output voltage is higher than a specified value or input voltage is lower than a specified value, the chip will enter protection mode to prevent abnormal function. As the die temperature is higher then 160\(^\circ\)C, the chip also will enter protection mode. The power MOSFET will be turned off during protection mode to prevent abnormal operation.

Inductor Selection
The recommended value of inductor for 10 WLEDs applications is from 10\( \mu \)H to 47\( \mu \)H. Small size and better efficiency are the major concerns for portable devices, such as the RT9293 used for mobile phone. The inductor should have low core loss at 1MHz and low DCR for better efficiency. The inductor saturation current rating should be considered to cover the inductor peak current.

Capacitor Selection
Input ceramic capacitor of 2.2\( \mu \)F and output ceramic capacitor of 1\( \mu \)F are recommended for the RT9293 applications for driving 10 series WLEDs. For better voltage filtering, ceramic capacitors with low ESR are recommended. X5R and X7R types are suitable because of their wider voltage and temperature ranges.

Thermal Considerations
For continuous operation, do not exceed absolute maximum operation junction temperature. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula :

\[
P_{\text{D(MAX)}} = \frac{(T_{\text{J(MAX)}} - T_{\text{A}})}{\theta_{\text{JA}}}
\]

Where \( T_{\text{J(MAX)}} \) is the maximum operation junction temperature, \( T_{\text{A}} \) is the ambient temperature and the \( \theta_{\text{JA}} \) is the junction to ambient thermal resistance.

For the recommended operating conditions specification of RT9293, the maximum junction temperature of the die is 125\(^\circ\)C. The junction to ambient thermal resistance \( \theta_{\text{JA}} \) is layout dependent. The junction to ambient thermal resistance for TSOT-23-6 package is 255\(^\circ\)C/W and for WDFN-8L 2x2 package is 165\(^\circ\)C/W on the standard JEDEC 51-3 single layer thermal test board. The maximum power dissipation at \( T_{\text{A}} = 25^\circ\text{C} \) can be calculated by following formula :

\[
P_{\text{D(MAX)}} = \frac{(125^\circ\text{C} - 25^\circ\text{C})}{(165^\circ\text{C/W})} = 0.606\text{W} \quad \text{for WDFN-8L 2x2 packages}
\]

\[
P_{\text{D(MAX)}} = \frac{(125^\circ\text{C} - 25^\circ\text{C})}{(255^\circ\text{C/W})} = 0.392\text{W} \quad \text{for TSOT-23-6 packages}
\]
The maximum power dissipation depends on operating ambient temperature for fixed $T_J(\text{MAX})$ and thermal resistance $\theta_JA$. For RT9293 packages, the Figure 7 of derating curves allows the designer to see the effect of rising ambient temperature on the maximum power allowed.

![Figure 7. Derating Curves for RT9293 Packages](image)

**Layout Consideration**

For best performance of the RT9293, the following guidelines must be strictly followed.

1. Input and Output capacitors should be placed close to the IC and connected to ground plane to reduce noise coupling.
2. The GND and Exposed Pad should be connected to a strong ground plane for heat sinking and noise protection.
3. Keep the main current traces as possible as short and wide.
4. LX node of DC-DC converter is with high frequency voltage swing. It should be kept at a small area.
5. Place the feedback components as close as possible to the IC and keep away from the noisy devices.

![Figure 8. The Layout Consideration of the RT9293](image)

### Table 1. Recommended Components for Typical Application Circuit

<table>
<thead>
<tr>
<th>Reference</th>
<th>Qty</th>
<th>Part Number</th>
<th>Description</th>
<th>Manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>1</td>
<td>SR26</td>
<td>Schottky Diode</td>
<td>PANJIT</td>
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<tr>
<td>$C_{\text{IN}}$</td>
<td>1</td>
<td>EMK107BJ225MA-T</td>
<td>Capacitor, Ceramic, 2.2µF/16V X5R</td>
<td>Taiyo Yuden</td>
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<tr>
<td>$C_{\text{OUT}}$</td>
<td>1</td>
<td>GMK107BJ105KA</td>
<td>Capacitor, Ceramic, 1µF/50V X5R</td>
<td>Taiyo Yuden</td>
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<tr>
<td>$R_{\text{SET}}$</td>
<td>1</td>
<td>RC0603FR</td>
<td>Resistor 15Ω, 1%</td>
<td>YAGEO</td>
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<td>L</td>
<td>1</td>
<td>NR4018T220M</td>
<td>Inductor, 22µH</td>
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Outline Dimension

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Dimensions In Millimeters</th>
<th>Dimensions In Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>A</td>
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<td>0.100</td>
</tr>
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<td>B</td>
<td>1.397</td>
<td>1.803</td>
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<tr>
<td>b</td>
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<td>0.559</td>
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<td>C</td>
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<tr>
<td>D</td>
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</tr>
<tr>
<td>e</td>
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<tr>
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</tr>
<tr>
<td>L</td>
<td>0.300</td>
<td>0.610</td>
</tr>
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</table>

TSOT-23-6 Surface Mount Package
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